SPACE TRANSPORTATION SOLUTIONS AND INNOVATIONS SYMPOSIUM (D2)
Launch services, Missions, Operations and Facilities (2)

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A DEBRIS CATALOG METHODOLOGY FOR BREAKUP ANALYSIS OF SPACE LAUNCH VEHICLES

Abstract

Flight safety analysis is required in order to estimate risk to the public, to involved parties, to other vehicles, and to property, from space launches, missile tests, etc. The flight safety analysis system to which this paper refers is the Range Safety Template Toolkit (RSTT) developed for the Australian Department of Defence. The RSTT has been described previously at the 2006 and 2008 Atmospheric Flight Mechanics Conferences. Such a system needs to consider all credible malfunctions and also nominal events in order to evaluate risk (both probability and severity). Most such failure modes involve the vehicle breaking into portions or fragments, usually through explosion or aerodynamic stresses. This method also covers a combination of explosion and aerodynamic breakup. Such breakups are caused by random processes hence statistical modelling is used. The path of these fragments through the atmosphere and to the ground is greatly affected by their properties, as is the damage they may do when striking another vehicle, person, structure, etc. The descriptions of these fragment properties are called debris catalogs. This paper describes both the debris catalog generation methodology, provided as a set of flowcharts, formulas, graphs and software tools; and the theoretical underpinning. In preparation, 'flight maps' are constructed to show the relevant stressors which may trigger various failure modes at flight phases – selected from thrust, mass, dynamic pressure, heat input, velocity, altitude. For each type of failure (inert, explosive and aerodynamic), several distinct conditions or times are identified at which debris catalogs will be generated. Guidelines are given to be sufficiently representative of the whole flight while not imposing too onerous a computation load. The mission used as an example results in the requirement for 14 debris catalogs to be derived. The first type of breakup is 'inert events'. Items include spent stages, fairings and payloads; and the consequences of failure to separate and failure to ignite. Industry best practice is described briefly. The second type of event is 'explosive breakup'. The paper includes an assessment of existing published explosion methodologies and finds them inconsistent and inadequate for handling the general case. It then describes explosion processes in some detail, combining both theory and observed cases. A tool is developed which qualitatively compares the released energy and the vehicle structural strength to estimate an 'explosion degree'. This is translated into a debris catalog using a fractal fragmentation model (described in a paper submitted as 180221). The effect of an exploding stage on neighbouring stages (ahead, behind or adjacent to) is also considered. The third type of event is 'aerodynamic breakup', the result of structural overloading, such as caused by defective manufacture, severe manoeuvring, a low trajectory, or re-entry. This is much more complex than explosions because breakup depends on the entire history of flight conditions. A significant tool is the tracking of possible 'attitude modes' of the vehicle – for example it may travel nose-first, or suffer excessive angle of attack, or tumble, depending on design deficiencies or failures. Each mode will impose aerodynamic and thermal stresses, which are compared to designed strengths in generic 'maps' or using mission specific analysis, giving a 'breakup

degree'. The fractal model is again applied to yield fragments. Failures often involve an explosion triggering aerodynamic breakup, or aerodynamic breakup triggering explosions. Such 'mixed' cases are handled equally well by the methodology. The newly-developed 'fractal fragmentation model' (described in a paper submitted as 180221) seamlessly covers the whole spectrum of events from aerodynamic breakup to explosions, including the problematic 'mixed' area such as explosions triggered by breakup. This model also covers all degrees of severity from a few fragments to thousands. The output is in terms of mass distribution and ballistic coefficients. The model is based on a theory of 'fractal fragmentation' whereby the 'degree' is estimated from the available energy (explosive or kinetic). The model has been tuned and tested against known cases of explosion and breakup, and stands up well.